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Vol. 30. No. 251. November 1944.

REPORT ON TESTS FOR SOIL STABILIZATION.

BY THE SOIL STABILIZATION PANEL OF THE STANDARDIZATION SUB-COMMITTEE NO. 7—ASPHALTIC BITUMEN.

1. The following report constitutes the first account of the discussions and work of the Soil Stabilization Panel of the Institute of Petroleum Standardization Committee. It will be supplemented from time to time by further reports indicating progress achieved.

2. Status and Terms of Reference of the Soil Stabilization Panel.

The Asphaltic Bitumen Sub-Committee of the Institute of Petroleum at a meeting held on the 13th January, 1943, decided to appoint a Panel to consider tests for use in connection with Soil Stabilization. In view of the function and scope of the Institute of Petroleum, the work has been confined to stabilization by means of products of a bituminous nature.

3. Constitution of the Soil Stabilization Panel.

The Panel has the following membership :—

Mr. L. G. Gabriel (in the Chair).
Mr. J. F. T. Blott.
Mr. I. Cameron (alternate Mr. A. E. Lawrence).
Dr. F. J. Gillbe.
Mr. J. S. Jackson (*ex officio*).
Mr. A. H. D. Markwick (alternates Mr. K. E. Clare and Dr. L. Maddison).
Mr. A. Osborn (alternate Dr. H. G. Williams).
Mr. A. R. Stark.

Co-opted members :

Dr. B. A. Keen, F.R.S. (later Dr. R. K. Schofield).
Mr. R. Glossop.

4. Plan of Work.

The Panel considered it to be highly important in discussing tests for soil stabilization to adopt a logical plan of attack. The plan adopted in compiling this schedule of tests was to review and classify tests placed before the Panel into Groups, in which the individual tests differed from each other only in detail. The procedure adopted in accumulating the data for examination was to take all known published schedules of tests, together with certain tests known to be in use in laboratories in this country. The variations of detail were eliminated after discussion by the Panel, and an agreed final procedure was adopted to replace the numerous variants previously in use. It was realized that although it was inevitable that the adoption of these new agreed versions of the tests might, to a certain extent,

cause difficulties in correlating new data with those previously obtained in any particular laboratory, it should provide for a great degree of interchangeability in the future between the results of different laboratories.

Where distinct methods of test exist covering similar properties of the materials (*e.g.*, the cone penetration resistance and the compression tests), no attempt has been made to eliminate one method in favour of the other where both are well established, but in certain cases attention has been directed to the main considerations for and against the alternative methods.

The Panel decided, in the first place, to concentrate on those tests which are devoted to evaluation of the properties of stabilized soil mixes, *i.e.*, the fundamental performance tests for stabilized soil. The schedule of tests presented with this report comprises certain tests which, in the opinion of the Panel, are of this type and suitable for standardization.

In addition to tests of the type discussed above, there may be a number of tests—one of which is included in the present report—which are used by individual laboratories, but which are not generally known and may be of recent development. In such cases the Panel may decide that certain of these methods are of sufficient interest to be included in the Schedule under the category of " tentative " tests.

In discussing the details of the tests now put forward for standardization, it has been found necessary to attempt a certain measure of definition of terms employed, and also to direct attention to certain fundamental considerations relevant to the practice of soil stabilization, without which the true terms of reference of the tests cannot accurately be appreciated. In this report, therefore, there are embodied notes on these matters which should be read in conjunction with the test procedures herewith presented.

5. Definition of Terms.

Soil.

The Panel has had before it the difficulty of defining accurately what is the meaning of " soil," and after very full discussion it has found itself unable to define soil in the sense at present under consideration.

Stabilization.

Soil stabilization involves the manipulation, treatment, and compaction of a soil in such a manner that it will remain in its initial compacted state without detrimental change in shape or volume when subjected to the stresses imposed by traffic or other agency and to the disintegrating and softening action of the weather and sub-soil water.

There are several distinct ways in which this can be done. Thus :—

(1) By imparting high internal friction to soil to promote resistance to deformation under stress (mechanical stabilization);

(2) By waterproofing designed to limit the ingress of water so that the material will not soften by absorbing water from the subgrade;

(3) By binding the grains of soil together either by the use of a cement or bituminous binders.

Frequently all three principles are applied in a single process.

Bituminous stabilization, with which alone the Panel is concerned, aims at providing mechanical stability—*i.e.*, capacity for supporting superimposed

loads without undue deformation, and resistance to such excessive absorption of water as would reduce the stability.

A subsidiary property which it is aimed to confer by bituminous stabilization is resistance to the disintegrating action of frost.

6. Interpretation of and Comments on the Schedule of Soil Stabilization Test Methods.

As indicated above, it was felt that it would be useful to record some of the reasons underlying the selection of the test conditions, and to discuss the nature of some of the problems which have to be solved.

Schedule.

The following tests are included in the present schedule :—

A.1. Preparation of Soil Mix.
A.2. Determination of Moisture Content.
A.3. Cone Penetration Resistance of a Compacted Stabilized Soil Mixture.
A.4. Compression Test.
A.5. Capillary Water Absorption Test.
A.6. Determination of the Bulk Density of Soil as present in Compacted Test Specimens of Stabilized Soil.
T.1. Water Absorption Test by Immersion.

"A" = Accepted test.
"T" = Tentative test.

Methods of Mixing and Compaction.

The processes which have been proposed for stabilizing soils cover a variety of petroleum products, and methods of operation. Thus the stabilizer may vary from a hard bitumen to a fluid oil or cutback, which may be applied as such or in the emulsified form, while the stabilizer may be incorporated into the soil with the aid of a stationary or travelling mixer or by mix-in-place methods. The methods used in practice are governed to a considerable extent by the type of stabilizer employed and by differences in construction technique which are likely to constitute important factors in the behaviour of the mix. Thus, for example, it is reported in the literature that the time and intensity of mixing can affect considerably both the mechanical stability and the water resistance of the compacted mix, but it does not necessarily follow that better results are obtained with the most thorough mixing. For these reasons, therefore, and since the investigation of a soil by the methods proposed will usually be made with a view to determining whether that soil can be successfully stabilized by a particular process, the Panel did not feel justified in presenting any standard mixing apparatus for the preparation of the soil mix, and has confined the standardization to certain treatments and precautions which are necessary to render the condition of the sample suitable for the subsequent testing operations. In Test Method A.I., however, it was thought advisable to recommend general methods of mixing which have been found suitable in the laboratory for oils and emulsions respectively, but it is recognized that

it may be desired to select some other method which is better suited to the particular process. It is recommended that in all cases details of the type of mixer used and the technique adopted should be given in reporting the results of the subsequent tests.

In regard to the compaction of the treated soil specimens, the question of the relation between conditions in practice and those in the test method is also one of importance. It is known that the degree of compaction achieved materially affects both the mechanical stability and the water resistance of the mix, but in view of the variations in compaction which are likely to occur under practical conditions, it is difficult to select one set of conditions in preference to another for test purposes. In addition, owing to differences in the size of the compacted specimens used in the different proposed tests, it is impossible for the moment to adopt conditions of compaction in the laboratory which are identical in every respect for all tests. Thus it is known that steady pressure of 3500-lb. total load as applied in Tests A.4 and A.5 does in fact normally produce densities higher than those obtained by the ramming technique of Test A.3 (similar to American Association of State Highway Officials (A.A.S.H.O.) designation T. 99–38) by about 5–10 per cent., according to the water content at which the measurements are carried out. It is also known that the densities given by the use of the steady pressure in Tests A.4 and A.5 are likely to be appreciably higher than those achieved in practice unless special attention is devoted to the compaction of the material, and for this reason the results given by Tests A.4 and A.5 may be more favourable than those actually obtained in the field. It is recommended that the method used for compaction and the densities obtained should be stated in reporting the results of tests.

7. Notes on Individual Tests.

*Test Method A.*1.

Instead of introducing a section on the preparation of the soil mix in the description of each test method, it was decided to give a general method of preparation as a separate test method. In accordance with the discussion given above, this method allows the variations of any particular process of stabilization to be taken into account.

*Test Method A.*2.

Owing to the possible presence of volatile components in the petroleum product used as stabilizer, the determination of the moisture content by drying in an oven is not likely to be satisfactory as a general method for a stabilized soil mix, and the distillation method I.P. 74/44 used for petroleum products has therefore been proposed by the Panel, and a suitable choice of the available alternatives in the original method is recommended.

*Test Methods A.*3 *and A.*4 (*Mechanical Stability Tests*).

The Panel was in general agreement that tests of the type which involve the measurement of the pressure necessary to extrude the compacted mix through an orifice at a constant rate were not to be recommended, owing to the empirical nature of the results, and while methods other than those adopted may give equally significant results, it was felt that the simplicity

of the cone-resistance test (A.3) and the compression test (A.4) rendered those methods most suitable for inclusion in the schedule.

The problem of measuring the load-bearing capacity is one of great complexity, on which there are many different points of view, and while the Panel is of the opinion that the tests adopted give measurements which will be qualitatively in line with the behaviour in practice and serve for comparing different mixes, no attempt is made to indicate their quantitative significance.

In regard to Test A.3, it is known that, with the mould specified (the standard mould used in A.A.S.H.O. T.99–38), the figures obtained may, in certain cases, be influenced by the proximity of the walls, and that the use of a mould of larger diameter would avoid this difficulty. This effect will, however, usually be slight, and since the test is not intended to have an exact quantitative significance, it was considered that the advantage of using a mould which is already standardized out-weighed the disadvantage mentioned.

The compression test A.4 has been developed largely in connection with the testing of soils stabilized with bitumen emulsions. The basic properties affecting the test results—*i.e.*, cohesion and internal friction of the soil—are the same as those governing the performance of stabilized soil specimens in the Cone Penetration Resistance Test A.3.

Test Methods A.5 and T.1 (Water Absorption Tests).

The Capillary Water Absorption Test A.5 is intended to simulate the weathering conditions that occur in the field when the subgrade is wet. The cylindrical test specimen is in contact with water over the base, and is allowed to absorb water for periods up to 28 days. If any changes in capillary properties of the material occur due to water absorption, the long duration of this test permits account to be taken of these. The test should be useful for all processes where the stability depends on the waterproofing of the soil.

In the different versions of the test now in use, various methods are specified for covering the walls, and in some cases the top of the soil cylinder with waterproof material. The Panel at first considered that it was advisable to cover both the walls and the top of the soil cylinder with an unperforated film of paraffin wax, in order to prevent entry of water at any part other than the lower face. Considerable discussion took place on the question of the possible influence of the top covering. With the top covered it was considered that water absorption would take place through the narrow pores of the specimen and air would be expelled through the wider pores; but, if this did not occur, the water absorption would be restricted by the development of an air pressure within the voids. Experimental work was done to check this point, and it was found that the anticipated restriction of entry of water was in fact very marked. It was therefore decided to recommend covering only the sides of the specimen, and this is the method adopted in Test Method A.5.

In the Rapid Water Absorption by Immersion, Test Method T.1, the rate of absorption of moisture is accelerated by increasing the exposed surface through which water can enter the sample and decreasing the effective thickness of the specimen by comparison with that used in other tests. In

this way it is possible to obtain results by immersion for a period of only 16 hours. This period is insufficient for any long-time changes to occur in the stabilized material due to absorption of water, and to curing of the material. Against this limitation, the test has definite advantages in the speed with which the results can be obtained.

Reproducibility of Tests.

It will be noticed that in the specified test methods no attempt has been made to fix the limits of reproducibility. It was felt that more experience will have to be gained in a greater number of test laboratories before these limits can be specified.

8. Future Programme.

In the immediate future, the Panel intend to consider standard methods for :—

(1) Determination of frost resistance of compacted mixes.
(2) Determination of stabilizer content of mixes.
(3) Sampling and treatment of samples in field testing.
(4) Standardization of methods of compaction applicable to all tests.

In regard to frost resistance, the Panel has already given the matter some consideration, and the following is a note on points brought out in discussion.

The need for adequate frost resistance is fully recognized by the Panel, but it was not found possible at the moment to include a test for this property. Methods in which isolated test specimens are subjected to cycles of freezing and thawing were discussed, but it was felt that such tests may not reproduce field conditions sufficiently closely. On the other hand, tests in which the specimen is frozen from the top downwards, with the base in contact with water, may be unduly severe. It was agreed that any decision on this question should be postponed until more information could be obtained on the correlation between the results of laboratory tests and experience in the field.

As regards methods of compaction adopted in preparing the test specimens for the various tests, the Panel has discussed at length the desirability of adopting procedures which will ensure that all tests are carried out on materials of approximately the same density.

In the absence of adequate field data, the Panel was unable to decide on the standard of density required, and therefore it proposed to investigate this matter in greater detail. The Panel will also endeavour to suggest the most desirable degree of compaction at which the tests should be carried out.

9. Methods of Test.

Test Method A.1. Preparation of Soil Mix.

1. *Introduction.*

This method describes the preparation of a soil mix having a desired water content and stabilizer content, for use in subsequent tests.

2. *Apparatus.*

(*a*) *B.S. Sieves.* No. 7 and $\frac{1}{8}$ in. B.S. 410 (1943).
(*b*) *Pestle and Mortar.* The mortar shall be at least 6 ins. in diameter.
(*c*) *Mixing Equipment.* An efficient laboratory mechanical mixer.

3. *Procedure.*

(*a*) The soil shall be air dried at 50 per cent. relative humidity to a state in which it may be crumbled. Normal air drying is generally a sufficient approximation to this condition of humidity.

Note.—Where there is no question of dispute, oven drying at temperatures not exceeding 110° C. may be used, but the results so obtained need to be checked against the results of the air drying method.

(*b*) The soil shall then be rubbed down gently in the mortar to reduce any aggregations which would be retained on the B.S.7 sieve. The whole sample shall then be thoroughly mixed and reduced by quartering until a representative sample of the necessary size is obtained. This sample shall then be screened through the B.S.7 sieve and the residue discarded.

(*c*) The moisture content of the fraction passing the B.S.7 sieve shall be determined by Test Method A.2. I.P.74/44. (In this case oven drying at 105–110° C. is also permissible.)

(*d*) The soil mix shall preferably be prepared by one of the methods suggested below, but it is recognized that other methods may have to be adopted when the test is used in relation to a particular process.

(*e*) The mix shall then be screened on the B.S. $\frac{1}{8}$-in. sieve and the residue gently rubbed or broken down in the mortar and re-screened until the whole of the mix has been passed through the sieve.

(*f*) It is recommended that a period of 24 hours shall elapse between the preparation of the soil mix and that of the test specimen, but it should be realized in this connection that many soils need a period of days before they reach equilibrium behaviour, so that this point should be watched in assessing the value of test results obtained.

4. *Recommended Mixing Technique.*

(i) *With an oil or asphaltic bitumen stabilizer.*

(*a*) The soil sample prepared as described under 3 (*b*) shall be placed in the mixing equipment, and sufficient distilled water added to give the final water content required. The material shall then be mixed for 10 minutes, or until it is judged by visual inspection that adequate dispersion of the water has been obtained.

(*b*) The required quantity of stabilizer and any other admixture shall then

be incorporated in a manner appropriate to the process of stabilization under consideration.

(ii) *With an emulsified oil or emulsified asphaltic bitumen stabilizer.*

(*a*) The soil sample prepared as described under 3 (*b*) shall be placed in the mixing equipment, and sufficient distilled water added to bring it approximately to the plastic limit. The material shall then be mixed for 10 minutes, or until it is judged by visual inspection that adequate dispersion of the water has been obtained. The required quantity of emulsion, diluted as considered necessary with distilled water, shall then be added to the soil and mixing started. Additional distilled water shall be added as necessary during the mixing to ensure a uniform distribution of the emulsified stabilizer. (This condition will usually be reached when the consistency of the mix is about that of soil when wetted to its liquid limit.) Any other admixture shall then be incorporated in a manner appropriate to the process of stabilization under consideration.

(*b*) The mixture shall then be allowed to dry in air until it reaches a consistency approximately equivalent to that obtained at the plastic limit, or until the water content is that required in the subsequent test.

5. *Reporting.*

The report giving the results of subsequent tests on the soil mix shall specify the technique used in the preparation of the mix.

Test Method A.2. Determination of Moisture Content.

The moisture content of the soil or of the soil mix shall be determined by Method I.P. 74/44 with the following details :—

Still.—Of type (i), (ii) or (iii) given under 2 (*b*).

Receiver.—25 ml. as given under 2 (*c*), Special Requirements (iv). The addition of 5 ml. of 10 per cent. caustic soda solution specified for bituminous emulsions shall be omitted.

Amount of sample.—100 gm.

Carrier Liquid.—Petroleum spirit, as given under 3 (*a*).

Test Method A.3. Cone Penetration Resistance of a Compacted Stabilized Soil Mixture.

1. *Introduction.*

This test gives a measure of the load-bearing capacity of a compacted stabilized soil mix. The test may be carried out on a single sample of soil mix selected for a specific purpose. Generally, however, results of greater significance are obtained by conducting a series of tests on samples of different water content, enabling the relationship between cone resistance and water content to be studied.

2. *Apparatus.*

(a) *Moulds.*—Cylindrical steel moulds each having a capacity of $\frac{1}{30}$ cu. ft. with an internal diameter of 4·0 in. and a height of approximately 4·6 in., and having a detachable collar assembly approximately 2½ in. in height; the mould and collar shall be attached to a detachable metal base (Fig. 1).

(b) *Cover Plate.*—Metal or glass plates to act as covers for the moulds.

(c) *Rammer and Guide.*—A cylindrical steel rammer 2 in. in diameter, and weighing 5½ lb., and any guide arrangements which will allow the rammer to be dropped freely and vertically through a distance of 1 ft. as shown in Fig. 2.

(d) *Cone Penetrometer.*—The cone shall be of steel, shall be right-angled, and have a rough surface. The surface may be conveniently roughened by means of concentric shallow V-shaped grooves, 40 to the inch. The dimensions of the cone are not specified, but a base diameter of about 2 in. is suitable. The cone shall be mounted on a shaft, and any type of penetrometer is permissible, provided it allows the shaft to move freely and vertically, is capable of applying the desired load, and is fitted with a locking screw and a device graduated in $\frac{1}{10}$ mm. for measuring the extent of the vertical movement of the shaft. The weight of the rod and cone assembly is not specified, but must be known and must not exceed about 5 kg. (see Fig. 3).

3. *Preparation of Specimen.*

(*a*) The soil mix prepared as described in Test Method A.1 shall be compacted into the mould in three equal layers to give a total compacted depth of about 5 in., each layer being compacted by twenty-five blows of the rammer dropping freely from a height of 12 in. above the upper surface of each finally compacted layer. The blows shall be distributed as evenly as possible over the surface of the specimen. In order to secure the best possible junction of successive layers, the top surface of each layer shall be loosened before the next portion is put in. After compaction, the collar shall be removed and the top of the soil specimen carefully trimmed level with the top of the mould with the steel straight edge.

(*b*) The moulds shall be covered with the cover plates and stored for 24 hours before the cone resistance is measured.

4. *Procedure.*

(*a*) The cone shall be adjusted until the tip makes scratch contact at the approximate centre of the surface of the prepared and stored specimen, and

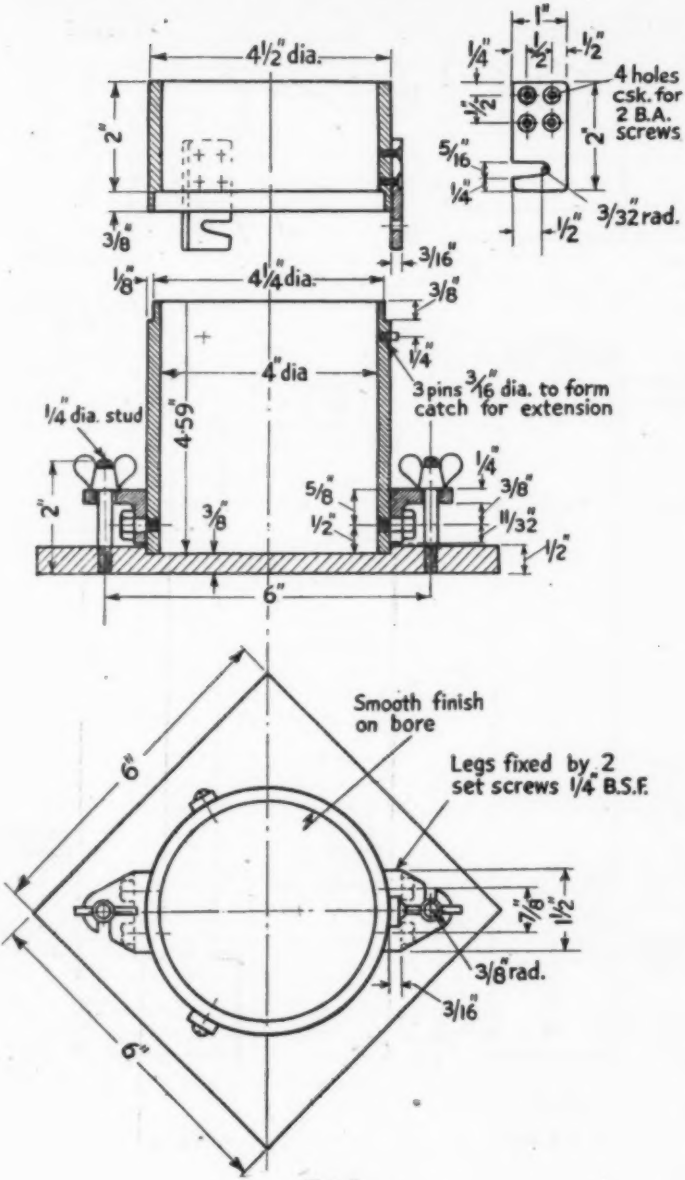

FIG. 1.
COMPACTION MOULD.

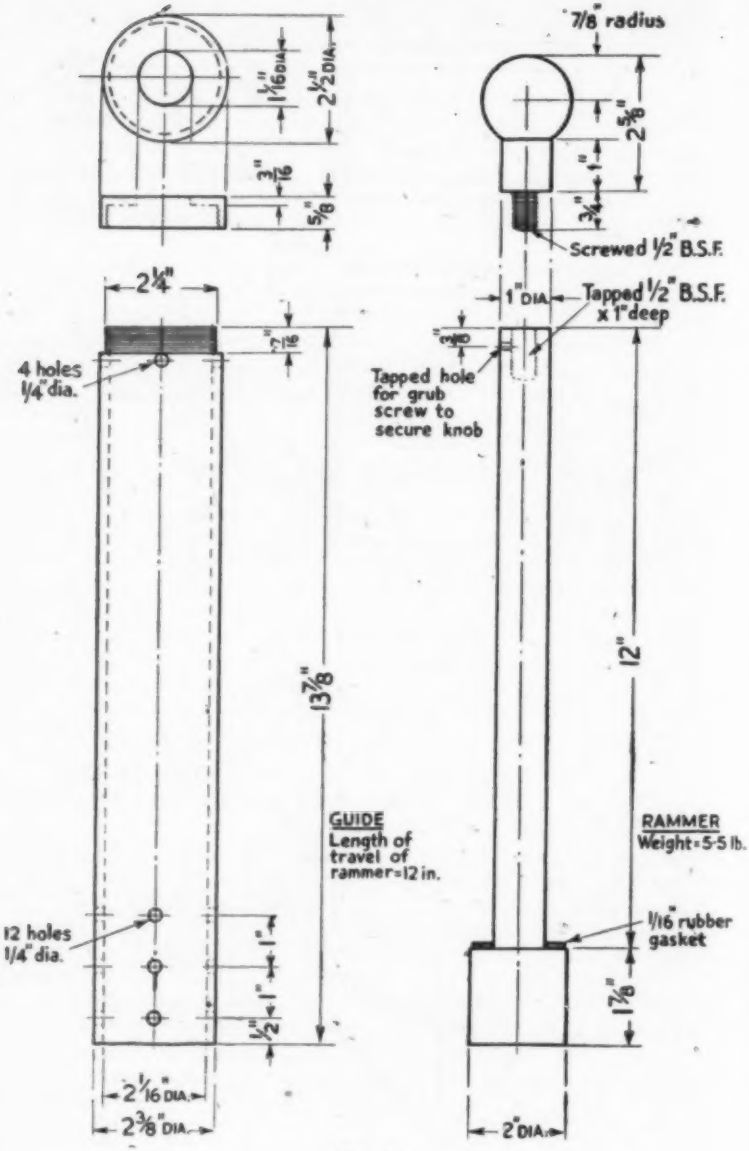

FIG. 2.

COMPACTION RAMMER AND GUIDE.

the penetrometer scale set to zero. The weight of the rod and cone assembly shall be applied gently by first supporting the cone with the fingers and then gradually releasing the finger pressure. One minute after allowing the full weight of the assembly to bear on the sample, the reading of the penetrometer scale shall be recorded.

(*b*) The locking screw shall be tightened, and additional weights added to the platform. An additional weight of 20–25 kg. is suitable for general purposes, but a smaller weight shall be used for specimens with low cone resistance, so that the total penetration of the cone shall not exceed 7 mm. For specimens with high cone resistance larger additional weights may be used provided that the total penetration does not exceed 7 mm. The cone shall be allowed to penetrate further under the additional load by releasing the load gently as before, and the penetrometer scale reading recorded two minutes after allowing the full weight to bear on the sample.

(*c*) The water content of the soil mixture shall be determined by means of test Method A.2 on a sample taken from the centre of the specimen immediately after penetration, and shall be reported with the result of the determination of cone penetration resistance.

5. *Calculation and Reporting.*

(*a*) The cone penetration resistance of the soil shall be calculated from the following formula :—

$$R = \frac{(\sqrt{W_2} - \sqrt{W_1})^2}{\pi(p_2 - p_1)^2}$$

where R = cone penetration resistance in kg. per sq. cm.
W_1 = weight in kg. of cone assembly.
W_2 = weight in kg. of cone assembly plus additional weight,
p_1 = penetration in cm. with load W_1,
p_2 = penetration in cm. with load W_2.

(*b*) The bulk density of the soil as present in the compacted specimen is determined according to Method A.6. and recorded.

(*c*) A curve shall be plotted of the relation : cone penetration resistance against water content.

Note.—The use of two different loads avoids both the necessity of registering the zero accurately, and the errors which would be caused by any imperfection in the tip of the cone. If the cone penetration resistance is measured directly instead of by the differential method, a small error in registering the zero leads to large errors in the cone penetration resistance. Thus an error of 1 mm. in registering the zero causes an error of about 37 per cent. for a mix of cone penetration resistance 20 kg. per sq. cm. when tested under a load of 30 kg.

With the differential method it is only necessary to register the zero approximately in order that the total penetration shall not exceed 7 mm. The figure of 7 mm. is specified, since the disturbing effect of the sides of the mould is likely to be introduced at larger penetrations.

Test Method A.4. Compression Test.

1. *Introduction.*

This test provides a measure of the load-bearing capacity of a compacted stabilized soil mixture. The test may be carried out as such on any particular sample, and is of special interest when conducted in conjunction with the Capillary Water Absorption Test (Test Method A.5.), measurements being made on specimens treated according to the present method and on corresponding specimens which have been submitted to Test Method A.5. A comparison of the results permits the evaluation of the change in bearing capacity due to the absorption of water.

2. *Apparatus.*

(a) *A press* capable of exerting a total load of at least 5000 lb., which may be used for compaction and extrusion of the specimen.

(b) A screw or hydraulic press, which can be controlled to give a regular increase in load of 20 lb. per second. This press may be the same as that described in Section 2*a*.

(c) *Mould.* A cylindrical steel mould, open at each end, 2 in. in internal diameter and 5 in. in length.

(d) *Plunger.* A solid steel cylindrical plunger, 6 in. in length, with a polished circular base which shall be a sliding fit in the mould.

(e) *Base Plate.* A steel plate which may conveniently be of dimensions 6 in. × 6 in. × $\frac{1}{4}$ in.

(f) *Tamping Rod.* A solid steel cylindrical rod, 8 in. in length and 1 in. in diameter.

3. *Preparation of Specimen.*

(*a*) The soil mix prepared as described in Test Method A.1 shall be tamped into the mould resting on the base plate in three approximately equal layers, each layer being tamped with twenty-five blows of the tamping rod, falling from a height of 1 ft. In order to secure the best possible junction of successive layers, the top surface of each layer shall be loosened before the next portion is put in. The moulds shall be filled to within about 1 in. of the top, and final compaction carried out by inserting the plunger and applying a load of 3500 lb. for 2 minutes.

This operation is best carried out by bringing the load to 3500 lb., then immediately releasing the pressure, ascertaining that the plunger is free in the mould, and finally increasing the load to 3500 lb. again and maintaining it for 2 minutes.

The specimen shall then be removed from the mould by extrusion in the press.

(*b*) The specimen shall be air dried until the loss in weight in 24 hrs. is less than 1 per cent. of the total loss in weight.

4. *Procedure.*

The specimen shall be placed in the press, and the load increased at the rate of 20 lb. per second. The maximum load shown on the gauge

before the sample collapses shall be noted. Three samples shall be tested.

5. *Reporting.*

(*a*) The pressure corresponding to the maximum loads recorded on each specimen shall be calculated, and the mean pressure evaluated and recorded.

(*b*) The bulk density of the soil as present in the compacted specimen is determined according to Method A.6 and recorded.

Test Method A.5. Capillary Water Absorption Test.

1. *Introduction.*

This test determines the resistance to water absorption of specimens of compacted stabilized soil.

2. *Apparatus and Materials.*

(a) *Mould.* A cylindrical steel mould, open at each end, 2 in. in internal diameter, and approximately 5 in. in length.

(b) *Plunger.* A solid steel cylindrical plunger 6 in. in length with a polished circular base which shall be a sliding fit in the mould.

(c) *Base Plate.* A steel plate which may conveniently be of dimensions 6 in. × 6 in. × ¼ in.

(d) *Compaction Apparatus.* A press capable of exerting a total load of at least 5000 lb., which may be used for compaction or extrusion of the soil specimens. Alternatively, a 5½-lb. rammer, with a guide arrangement which will permit it to be dropped freely and vertically through a distance of 1 ft. may be used in conjunction with a suitable press for extruding the specimen.

(e) *Absorption Bath.* A vessel closed with a tightly fitting lid and containing a layer of distilled water of sufficient depth to bring the level to a height of approximately 2 mm. above a horizontal perforated zinc shelf on which the soil cylinder rests. The level of the water shall be maintained by means of a suitable water feeding device.

(*f*) *Wire brush* with short stiff wires.

(*g*) *Waxing Equipment.* This shall consist of a metal plate with a smooth upper surface, which shall be kept horizontal. The upper surface shall be covered with a thin film of paraffin wax maintained in a molten state by means of a gas burner or other source of heat.

Paraffin waxes having melting points of about 50° C. and composed of fine crystals have been found suitable. To avoid the danger of contaminating the specimen with acids formed by oxidation of the wax on continued heating, fresh wax should be used on each occasion.

3. *Preparation of Specimen.*

(*a*) The water content of the soil mix prepared as described in Test Method A.1 shall be determined by Test Method A.2 on a sample taken immediately before proceeding with the following operations.

(*b*) The mould shall be stood upon the base plate, and the soil mix introduced in approximately three equal layers, which are gently tamped with the tamping rod. In order to secure the best possible junction of successive layers, the top surface of each layer shall be loosened before the next portion is put in. Sufficient material shall be added to bring the level of the mix to within about 1 in. of the top of the mould.

(*c*) The plunger shall then be inserted in the mould and the soil mixture compacted by either of the following methods :—

(i) Compression in the press to a total load of 3500 lb. (1600 kg.). This is best done by raising the load to 3500 lb., then immediately

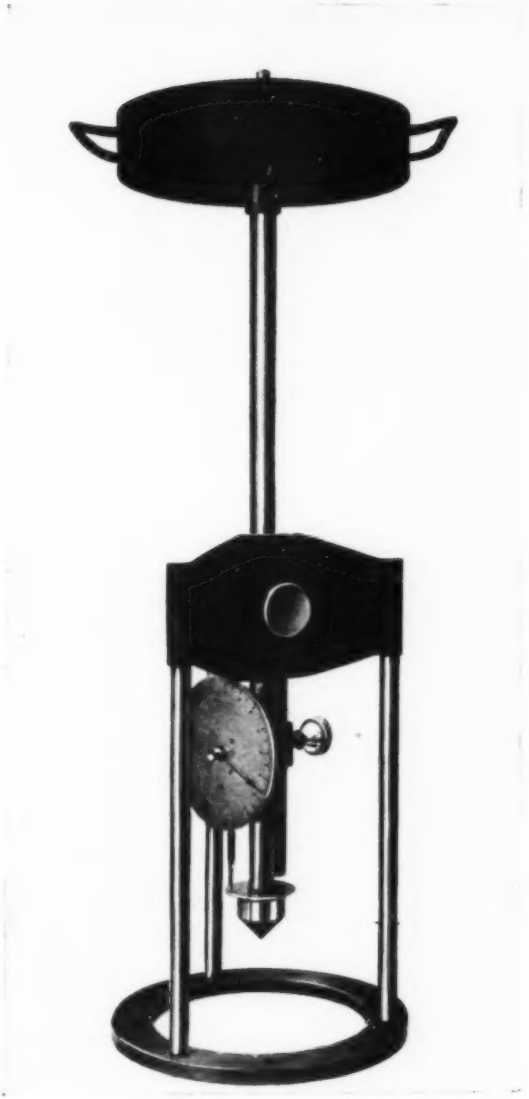

FIG. 3.
CONE PENETROMETER.

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FIG. 5.

METAL CARRIER, SHOWING SPECIMEN IN PLACE WITH FILTER PAPER COLLAR ATTACHED.

releasing the pressure, ascertaining that the plunger is free in the mould, and finally raising the load to 3500 lb. again, maintaining this load for 2 minutes.

(ii) Compaction, using the rammer-and-guide arrangement. The head of the plunger shall be submitted to sixty blows of the rammer falling freely through a height of 1 ft.

(*d*) The base of the compacted specimen shall be extruded from the mould to a distance of approximately 2 mm. by means of the press. The extruded portion of the specimen shall then be removed by wire brushing. By means of the press, the specimen shall then be removed from the mould.

(*e*) If so desired, the specimen shall now be allowed to dry out in air until the loss in weight in 24 hours is less than 1% of the total loss in weight.

(*f*) The specimen either at the water content of compaction or after drying as specified under 3 (*e*) shall then be coated over the wall with a thin film of paraffin wax, by bringing the surface into contact with the waxing plate, avoiding waxing the base and top of the cylinder.

(*g*) Except when allowed to dry as described under 3 (*e*), the waxed specimen shall then be stored for 24 hours, supported above the water level in the absorption bath.

(*h*) The specimen shall then be weighed to the nearest 0·1 g.

4. *Procedure.*

(*a*) The specimen shall be stood in the absorption bath, with the wire-brushed face downwards and immersed in water to a depth of 2 mm. The bath shall be closed and kept at room temperature, which shall be recorded.

(*b*) After one day the specimen shall be removed, the surface cautiously dried with filter paper and weighed to the nearest 0·1 g. It shall then be replaced in the absorption bath and reweighed, as before, at convenient intervals.

5. *Calculation and Reporting.*

(*a*) The results shall be recorded as the total increases in weight after intervals of, for example, 1, 2, 3, 4, 7, 14, 21 and 28 days, either by plotting or by tabulation.

(*b*) When the specimen is immersed without drying out in air, the moisture content determined under 3 (*a*) shall be recorded as the moisture content before immersion. In cases where the specimen is dried out in air this shall be stated.

(*c*) The average room temperature over the period of immersion shall be recorded.

(*d*) The method used for compaction shall be stated.

(*e*) The bulk density of the soil as present in the compacted specimen is determined according to Method A.6. and recorded. In cases where wire brushing produces a very rough surface, this figure can only be approximate.

Test Method A.6. Determination of the Bulk Density of Soil as Present in Compacted Test Specimens of Stabilized Soil.

1. *Introduction.*

This method describes the determination of the amount of solid mineral matter in test specimens of compacted soil as required for use in Test Method A.3–A.5 and Method T.1.

2. *Specimen for Cone Penetration Resistance Test.*

Procedure.

(*a*) After the cone penetration resistance of the specimen has been determined, and before the moisture content has been determined, the mould containing the specimen shall be weighed to the nearest 1 g. $W(m + s)$.

(*b*) The sample shall be removed from the mould and shall be cut down the centre. Two specimens of appropriate size shall be removed from the middle of the two halves of the specimen.

(*c*) The moisture content of one of these samples shall be determined by the procedure given in Method A.2. Let this moisture content be m per cent.

(*d*) The stabilizer content of the other sample shall be determined by an appropriate method. Let this stabilizer content be s per cent. (see Note).

(*e*) The empty mould shall be weighed to the nearest 1 g. (W_m).

Calculation and Reporting.

(*a*) The weight in grams of the compacted specimen shall be calculated from the formula :

$$\text{Weight of specimen} = W_s = W_{(m+s)} - W_m.$$

(*b*) The bulk density of the specimen shall be calculated from the formula :—

$$\text{Bulk density of specimen (lb./cu. ft.)} = D_w = \frac{30 \times W_s}{453{\cdot}59} = \frac{W_s}{151{\cdot}2}.$$

(*c*) The bulk density of the solid mineral matter in the compacted specimen shall be calculated from the formula :—

$$\text{Bulk density of soil (lb./cu. ft.)} = D_s = \frac{D_w \times 100}{100 + m + s}.$$

3. *Specimen for Capillary Water Absorption or Compression Test.*

Procedure.

(*a*) After the specimen has been extruded from the mould, but before it has been subjected to either the capillary water absorption or the compression test, it shall be weighed to the nearest 0·1 g. (W_s).

(*b*) The height of the specimen shall be determined to the nearest 0·05 in. This shall be done by measuring the height in a direction parallel to the axis of the specimen, and at four diametrically opposite points. The mean of these four measurements shall be taken as the height (h) in inches.

(*c*) The moisture content of the mix from which the specimen was made

shall be determined by Test Method A.2. Let this moisture content be m per cent.

(*d*) The stabilizer content of the specimen shall be determined by an appropriate method. Let this stabilizer content be s per cent. (see Note).

Calculation and Reporting.

(*a*) The volume of the compacted specimen shall be calculated from the formula :—

$$\text{Volume of specimen (cu. ft.)} = V_s = \frac{\pi h}{1728} = \frac{h}{550}.$$

(*b*) The bulk density of the soil, water, and stabilizer in the compacted specimen shall be calculated from the formula :—

$$\text{Bulk density (lb./cu. ft.) of specimen} = D_w = \frac{W_s}{453{\cdot}59 \times V_s}.$$

(*c*) The bulk density of solid mineral matter in the compacted specimen shall be calculated from the formula :—

$$\text{Bulk density of soil (lb./cu. ft.)} = D_s = \frac{D_w \times 100}{100 + m + s}.$$

4. *Specimen for Rapid Water Absorption Test by Immersion.*

Procedure.

(*a*) The moisture content of the mix from which the specimen was made shall be determined by Test Method A.2. Let this moisture content be m per cent.

(*b*) The stabilizer content of the specimen shall be determined by an appropriate method. Let this stabilizer content be s per cent. (see Note).

Calculation and Reporting.

(*a*) The weight of the specimen in grams shall be calculated from the formula :—

$$\text{Weight of specimen} = W_s = W_2 - W_1 - w_1$$

where W_2, W_1, and w_1 are the weights determined for the carrier, filter paper and specimen; for the carrier; and for the dry filter paper, in Test Method T.1.

(*b*) The bulk density of soil water and stabilizer in the compacted specimen shall be calculated from the formula :—

$$\text{Bulk density of specimen (lb./cu. ft.)} = D_w = \frac{W_s}{453{\cdot}59 \times 0{\cdot}01152} = \frac{W_s}{5{\cdot}22}.$$

(*c*) The density of solid mineral matter in the compacted specimen shall be calculated from the formula :—

$$\text{Bulk density of soil (lb./cu. ft.)} = D_s = \frac{D_w \times 100}{100 + m + s}.$$

Note.—In the laboratory the weight of stabilizer originally added to the mix will generally be known and may be adopted for purposes of calculation. Where an actual determination has to be made, this can be effected by one of the published methods involving solvent extraction.

Test Method T.1. Water Absorption Test by Immersion.

1. *Introduction.*

This test provides a means for the rapid determination of the resistance to water absorption of a compacted stabilized soil mixture. In view of its rapidity, the method is specially suitable for testing samples on the construction site.

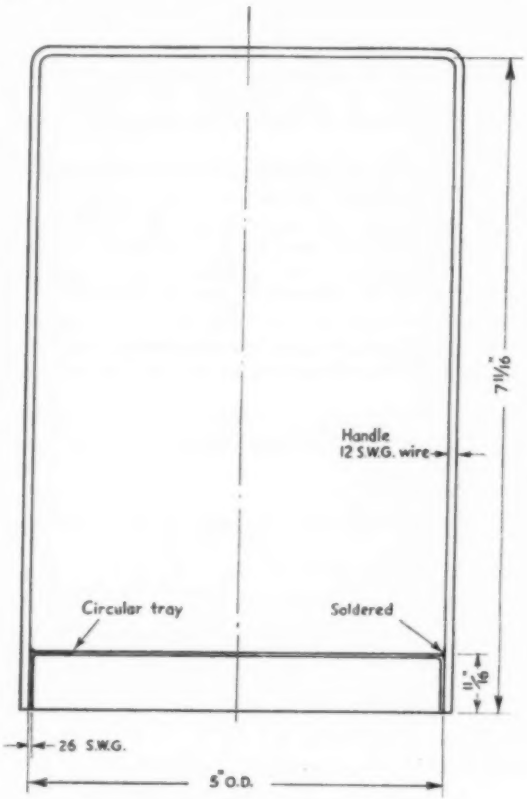


Fig. 4.

CARRIER FOR IMMERSION SPECIMEN.

2. *Apparatus.*

(*a*) *Moulds.* Cylindrical steel moulds each having a capacity of $\frac{1}{30}$ cu. ft. with an internal diameter of 4 in. and a height of approximately 4·6 in. and having a detachable collar assembly approximately $2\frac{1}{2}$ in. in height; the mould and collar shall be attached to a detachable metal base (Fig. 1).

(b) *Rammer and Guide.* A cylindrical steel rammer, 2 in. in diameter and weighing 5½ lb., and any guide arrangement which will allow the rammer to be dropped freely and vertically through a distance of 1 ft. as shown in Fig. 2.

(c) *Brass Cylinder.* A brass cylinder, 3 in. high and 4 in. in diameter, which shall be a sliding fit in the compaction mould. This cylinder is inserted into the mould to reduce the volume of the resulting specimen to about one-third of the standard compaction specimen.

(d) *Extraction Device.* A jack or other device suitable for removing the specimen from the mould.

(e) *Straight Edge.* A steel straight edge not less than 6 in. in length.

(f) *Metal Carrier* of the type and dimensions shown in Fig. 4.

(g) *Filter Paper,* 12·5 cm. in diameter (*e.g.,* Whatman No. 44).

3. *Preparation of Specimen.*

(a) The moisture content of the soil mix prepared as described in Test Method A.1 shall be determined by Test Method A.2.

(b) The brass cylinder shall be placed in the mould and about 100 g. of the soil mix added. This portion of mix is tamped lightly into the corners of the bottom of the resulting mould in order to form a good edge on the lower face of the specimen. 600–700 g. of mix shall then be placed in the mould and compacted by twenty-five blows with the rammer falling freely through a height of 1 ft. The blows shall be distributed as evenly as possible over the surface of the specimen. The collar shall then be removed, and the upper face of the specimen trimmed level with the top of the mould with the straight edge.

4. *Procedure.*

(a) A carrier shall be weighed to the nearest 1 g., and the filter paper placed on the tray. The specimen shall then be placed on the filter paper and the assembly weighed to the nearest 1 g. A strip of filter paper 1¾ in. in width shall then be fixed round the specimen in the form of a collar (Fig. 5).

(b) The assembly shall then be immersed in water at room temperature, so that the upper surface of the specimen is maintained 1 in. below the surface of the water.

(c) After 16 hours' immersion the assembly shall be withdrawn from the bath, the collar carefully removed, the free surface water on the specimen and carrier removed with the aid of filter paper and the assembly weighed to the nearest 1 g.

(d) The average room temperature during the period of immersion shall be recorded.

5. *Calculation and Reporting.*

(a) The water absorption of the specimen shall be calculated from the following formula :—

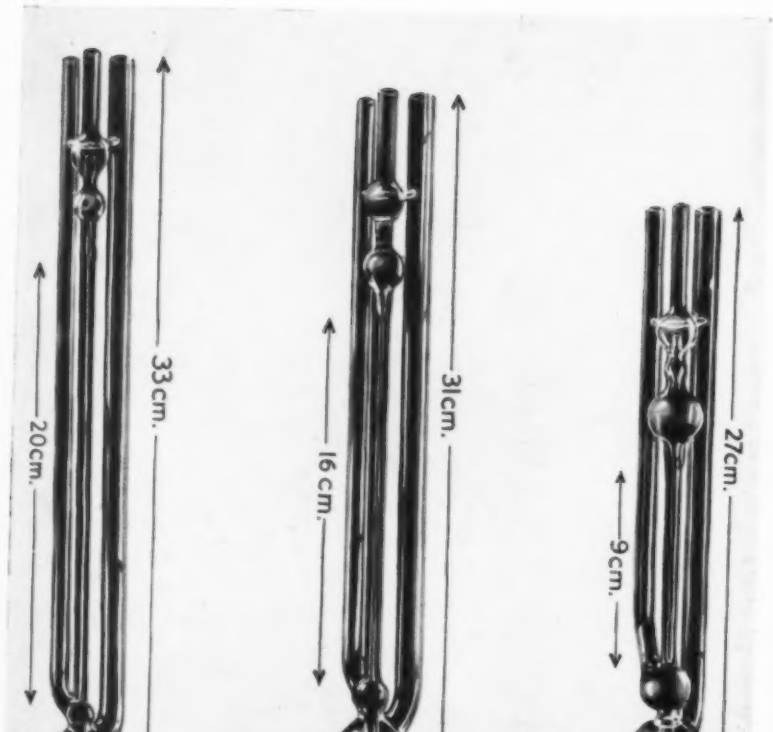
$$W_a = \frac{(W_3 - W_2 - w_2 + w_1)\,(100 + m + s)}{W_2 - W_1 - w_1}$$

Where W_a = g. of water absorbed per 100 g. of dry soil.
W_1 = weight of carrier (g.).
W_2 = weight of carrier + dry filter paper + dry specimen (g.)
W_3 = weight of carrier + wet filter paper + wet specimen (g.).
w_1 = weight of dry filter paper (g.)
w_2 = weight of wet filter paper (g.) (see Note).
m = original moisture content of specimen (per cent).
s = stabilizer content of specimen (per cent).

Note.—The value to be taken for w_2 shall be determined by removing the specimen from the carrier after an immersion test, and carefully scraping any loose soil off the filter paper. The exposed parts of the carrier shall then be dried, and the carrier with the wet filter paper on it weighed to the nearest 1 g. Since the weight of the carrier (W_1) is known, the weight of the wet filter paper (w_2) can be calculated.

(*b*) The bulk density of the soil as present in the compacted specimen is determined according to Method A.6 and recorded.

(*c*) The water absorption shall be reported to the nearest 0·2 gm., and the bulk density to the nearest whole number.



MICRO VISCOMETER
TEST VOLUME 2 ML.

MINIATURE VISCOMETER
TEST VOLUME 5 ML.

SHORTENED VISCOMETER
TEST VOLUME 15 ML.

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MINIATURE AND MICRO SUSPENDED LEVEL VISCOMETERS.

By M. M. Lapitzky and S. Thompson.

The need has often been felt for a viscometer for use in the determination of viscosity when, for various reasons, only a small quantity of oil is available. A particular case in point is the determination of the K.V.I. of the mineral-oil portion separated from compounded oils and from greases. The normal suspended level viscometer (I.P. 71/44T) requires about 20 ml. of oil for a determination, whilst the quantities normally available from compounded oils or greases rarely exceed 5–6 ml. and are usually of the order of about 2 ml. Suspended level viscometers were therefore constructed for this work, the design being based on the Fitzsimons modification of the Ubbelohde Suspended Level Viscometer. By modifying the filling bulb and making it spherical, elongating the capillary, reducing the volume of the timing bulb, and altering the shape of the suspended level bulb, miniature and micro viscometers have been constructed, the former requiring 5 ml. and the latter as little as 2 ml. of oil, whilst retaining the accuracy prescribed by the I.P. for Method 71/44T.

The lengthening of the capillary has made it possible to time the flow of a very small volume of oil without appreciably decreasing the diameter of the capillary from that of the corresponding suspended level viscometer of the normal design.

According to Hagenbach's formula for calculating the kinetic energy correction, the 2-ml. viscometer should have a " B " factor approximately one-tenth of that used for the normal type of instrument, and this could be disregarded for normal routine work.

It has been found necessary in certain cases, particularly at low temperatures, to use the suspended level viscometer in shallower baths than those normally used. An application of some of the modifications described above has enabled a shortened viscometer to be constructed which, whilst retaining the specified volume of the timing bulb and the specified length of capillary, has a total length about 60 mm. shorter than the normal type of instrument.

A table showing typical results obtained on normal and micro types of viscometers is appended, and photographs of the micro, miniature, and shortened types described are shown opposite.

The authors wish to express their thanks to the " Shell " Refining and Marketing Co., Ltd., for permission to publish this article.

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A.S.T.M. Standard Methods of Test for Kinematic Viscosity—A.S.T.M. Designation D.445–42T.

Ogden Fitzsimons, " A Rapid Precision Viscometer," *Industr. Engng Chem., Anal.*, 1935, **7**, 345.

	Micro Type Suspended Level Viscometer.			Standard Type Suspended Level Viscometer.		
	Flow time in seconds.	Factor.	Kinematic Viscosity in c.s.	Flow time in seconds.	Factor.	Kinematic Viscosity in c.s.
Oil A.	234·75 234·76 234·73 234·73 234·70	C = 0·9516 B = 0·2	223·37	227·63 227·50 227·55 227·48 227·43	C = 0·9832 B = 2·8	223·69
	Av. 234·73			Av. 227·52		
Oil B.	544·05 543·93 544·06	C = 0·08875 B = 0·2	48·28	529·46 529·88 530·16	C = 0·09129 B = 2·8	48·37
	Av. 544·01			Av. 529·83		
Oil C.*	75·60 75·61	C = 0·8924 B = 0·2	67·47	66·70 66·70	C = 1·0144 B = 2·8	67·62
	Av. 75·60			Av. 66·70		
Oil D.	188·35 188·30 188·31	C = 0·12334 B = 0·2	23·23	218·34 218·40 218·34	C = 0·10652 B = 2·8	23·25
	Av. 188·32			Av. 218·36		

* Oil C shows that good correlation is obtained between the micro and normal types of viscometer using an oil with a flow time much lower than the minimum of 120 seconds prescribed by the I.P. (The lowest flow time permitted by the A.S.T.M. is 80 seconds.)